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WESTINGHOUSE

ASTRONUCLEAR LABORATORY

PRELIMINARY HAZARDS SUMMARY

FOR

NERVA IRRADIATION TESTING

AT

PLUM BROOK REACTOR FACILITY

Date: January, 1963

PREPARED BY: TEST PLANNING AND ANALYSIS

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1.0 INTRODUCTION

1.1 Type of Experiment

1.1.1 Purpose and Accomplishments

The irradiation tests for the NERVA program will involve the use of the horizontal through tube (HT-1) at Plum Brook. To simulate the NERVA environment, facilities will be required to permit testing of irradiated test samples at cryogenic temperatures. This will be accomplished by placing test samples in an enclosed capsule and inserting this capsule into the horizontal through tube. Remotely operated handling devices will be installed in the quadrant "C" portion of the reactor. The capsule will be maintained at the desired temperature by means of a cryogenic loop.

1.1.2 Location

The experiments are to be conducted at the NASA Plum Brook Reactor Facility, Sandusky, Ohio. The HT-1 test hole located in quadrant "C" will be used for the experiment.

1.1.3 Element Cooling

The test element will be cooled by the circulation of gaseous helium at the desired mass flow rate in a closed loop.

1.2 Experiment Objectives

The objective of the test is to study the performance and behavior of materials and components at gas flow, heat flux, neutron flux and temperature conditions of the NERVA program application. The loop will be designed to supply helium to the test sample in the capsule at a temperature of $50^{o}R$. This gas will be capable of absorbing heat within the capsule at a rate of 20 KW at the $50^{o}R$ temperature.

1.3 Test Sample

Test samples to be subjected to irradiation will consist of the items listed in Table I. Environmental conditions for the tests include cryogenic temperatures from $38^{o}R$ to ambient and integrated thermal and fast neutron fluxes up to 1.1×10^{20} nvt and 5.4×10^{19} nvt, respectively. An integrated gamma dose up to 5×10^{10}R (4.4×10^{12} ergs gm^{-1} (C)) will be experienced in some tests with up to 50 hours of irradiation time required. It should be noted that the tests listed include only those at low temperatures. Fueled samples and higher temperature range tests will require different capsule designs.

1.4 Loop Flow Diagram

System piping and components for the cryogenic loop are shown in Figure 2. It should be noted that the specific temperatures, pressures and flow rates shown on the schematic represent approximate conditions expected under normal conditions. It is conceivable that samples producing less than 20 KW could be tested at lower temperatures than 50°R.

1.5 Utility Requirements

The utility requirements for the testing program are listed in Tables II and III.

1.6 Capsule Handling and Checkout Procedure

After a test sample has been installed in the capsule and the assembly is complete, the following procedure will apply:

a) Make continuity tests of all capsule instrumentation and power leads from the experiment control room patch panel to insure good connections and proper orientation of sensing devices.

b) Pressurize the capsule pressure envelope with helium by cracking open the capsule helium supply isolation valve on the helium recirculating system. When the capsule reaches normal operating pressure, close the helium supply valve; and monitor the local pressure gage for pressure drop.

c) Start capsule vacuum pump, and commence pulling vacuum on the capsule vacuum jacket. If operating vacuum pressure cannot be attained, a helium to vacuum leak can be assumed; and the capsule end plug will have to be removed for inspection.

d) Insertion console operator insures proper phone communications with hot cave operator.

e) Hot cave operator closes quadrant wall tube door, insures that the tube drain is shut and relieves pressure from inflatable seal.

f) Release "in" position lock on quadrant wall insertion tray by means of "lock release" pushbutton on vapor container control console.

g) Withdraw capsule from quadrant wall tube by means of the quadrant wall insertion tray "in-out" switch on vapor container control console. Hot cave operator checks quadrant wall tube door for leaks.

h) When capsule reaches full "out" position, close quadrant wall tube valve manually from 0 ft. level above quadrant.

i) Swing polar crane into position, and secure pickup device to the capsule "middle section".

j) Release quadrant wall insertion tray clamp from the capsule "middle section".

k) Pick up capsule from quadrant wall insertion tray, and transfer it to the HT-1 insertion tray.

l) When the capsule is in proper position on the HT-1 slide drive, secure its clamp to the capsule "middle section" and remove the pickup device.

m) Complete capsule cooldown and final checkout of instrumentation.

n) Vapor container control console operator insures proper communications with the experiment control room.

o) Insert the capsule into the HT-1 inflatable seal by means of the HT-1 tray "in-out" switch on the vapor container control console until position lock 1 engages.

p) Inflate the inflatable seal to insertion pressure.

q) Open HT-1 motor operated gate valve by means of the "open" pushbutton on the vapor container control console.

r) When permission is received from the experiment control room to "insert capsule", release position lock 1 by means of "lock release" pushbutton on vapor container control console.

s) Insert the capsule to full "in" position by means of the HT-1 tray "in-out" switch on the vapor container control console, and insure that position lock 2 is engaged.

t) Engage the clamp on the HT-1 and capsule flanges by means of the "engage" pushbutton on the vapor container control console.

u) Inflate the inflatable seal to operating pressure.

v) Notify the experiment control room that the capsule is fully inserted and secured.

w) Shift "capsule withdrawal control" to the experiment control room.

x) When sample irradiation is complete, insure proper phone communications among all stations.

y) Shift "capsule withdrawal control" to the vapor container control console.

z) Reduce inflatable seal pressure to withdrawal pressure.

aa) Disengage the clamp from capsule and HT-1 flanges by means of the "disengage" pushbutton on the vapor container control console.

bb) Obtain permission from the experiment control room to "withdraw capsule".

cc) Release position lock 2 by means of "lock release" pushbutton on the vapor container control console.

dd) Withdraw capsule by means of the HT-1 tray "in-out" switch on the vapor container control console.

ff) Relieve pressure from HT-1 inflatable seal.

gg) Release position lock 1 by means of "lock release" pushbutton on the vapor container console.

hh) Withdraw capsule to the full "out" position by means of the HT-1 tray "in-out" switch on the vapor container control console. Commence capsule warmup from the experiment control room with the cryogenic system.

ii) Swing polar crane into position, and secure the pickup device to the capsule "middle section".

jj) Release HT-1 insertion tray clamp from the capsule "middle section".

kk) Pick up the capsule from the HT-1 tray, and transfer it to the quadrant wall insertion tray.

ll) When the capsule is in proper position on the quadrant wall tray, secure its drive slide clamp to the capsule "middle section" and remove the pickup device.

mm) Secure proper communication with the hot cave operator.

nn) Manually open the quadrant wall tube gage valve from the 0 ft. level above the quadrant.

oo) Hot cave operator checks quadrant wall tube door for leaks.

pp) Insert the rear end of the capsule into the quadrant wall tube to the full "in" position, and insure that the full "in" position lock is engaged.

qq) Inflate the quadrant wall tube inflatable seal.

rr) Vapor container console operator directs hot cave operator to drain the quadrant wall tube and observe whether the inflatable seal is sealing properly.

ss) Direct hot cave operator to open the quadrant wall tube door.

tt) When the capsule warmup is complete, manually valve the cryogenic system to recirculate conditions; and isolate the capsule under direction of the experiment control room.

uu) Bleed helium pressure from the capsule with bleed valve in basement area.

vv) Secure capsule vacuum pump and break vacuum. The capsule is now ready for disassembly and sample removal.

2.0 DESCRIPTION OF EQUIPMENT AND FACILITIES

To perform the tests in the horizontal through tube, various modifications and additions to the existing facilities are required. These additions and modifications are shown in Figure 1.

2.1 Capsule

A capsule will house the test samples. This inpile capsule is a cylindrical aluminum tube having a varied diameter. For descriptive purposes, three sections of the capsule are considered. The "front section", which will be inserted into the horizontal through tube (HT-1) for irradiation, will be approximately 8 1/2" in outside diameter and 9' 8" in length. This section is connected by means of a flange to a "middle section". The "middle section" will be approximately 11 1/2" in diameter and 3' in length. A "rear section", which will be inserted into the quadrant wall through tube for specimen removal, will be approximately 11 1/2" in diameter and 5' in length.

2.1.1 Front Section

The "front section" shown in Figures 4, 5, and 6 will house the test samples. It will be a cylindrical shell with one end closed with a hemispherical head and the other end opened to the "middle section". The "front section" contains a helium supply pipe, helium return pipe and sample container. The outer shell of the "front section" terminates at the start of the "middle section" by means of a flange. Helium piping will be installed concentrically within the outer shell and will be continuous to the "middle section". The helium supply pipe will be constructed in sections which can be disconnected at various points for removal to provide access to the test samples. In effect, the helium inlet pipe may be considered as a pull rod for the sample container. The helium return line will house the specimen supply pipe and will be sealed at the front end with a welded hemispherical head so that a vacuum can be pulled between it and the outer shell. Since a portion of the helium piping in this section will be exposed to high gamma heating, the piping will be designed for minimum mass consistent with pressure code requirements.

a) Materials

1) Drawn aluminum tube 6061-T6 will be used for the outer shell and the supply and return piping.

b) Design

1) The outer shell of the "front section" will be designed with consideration given to the 160 psia primary coolant water in the through tube, the forces due to capsule insertion, interior forces resulting from piping failure and normal handling stresses.

2) The helium piping will be designed with consideration given to forces due to specimen insertion, stresses due to the extreme temperature gradients and the 115 psia internal loop pressure.

3) All portions of the capsule directly affected by pressure are designed in accordance with the ASME Unfired Pressure Vessel Code, Section VIII.

2.1.2 Middle Section

This section (shown in Figure 7) will consist of an outer shell, helium inlet pipe connections, helium return pipe connections, a helium supply pipe continuous from the "front section" and a helium return pipe. Also, this section will contain a penetration for the capsule and specimen instrumentation lines. All instrumentation lines and piping will enter the capsule at this "middle section". The variation in diameter between the "middle section" and "front section" is accomplished by means of a flange. There will also be a flange on the opposite end of the "middle section" which separates the middle and rear sections.

a) Materials

The outer shell, flanges, inner piping and all connectors in the "middle section" will be constructed of AISI type 300 series stainless steel tubing.

b) Design

1) The outer shell will be designed with consideration given to the forces resulting from the insertion device and other handling stresses (see insertion mechanisms discussion).

2) The flange separating the "middle section" from the "front section" will be designed to resist the primary coolant water pressure, which will result if the inflatable seal mechanism fails (see HT-1 seal mechanism discussion). The flange, which separates the "middle section" from the "rear section", will be designed to resist the quadrant water pressure occurring at the time of specimen removal (see quadrant wall through tube seal mechanism discussion).

3) Inner piping of the "middle section" will be designed to resist temperature gradient stress and cryogenic loop pressures.

2.1.3 Rear Section

The "rear section" will consist of an outer shell, inner sample removal shell and a removable plug. The outer shell will, in effect, be continuous from the "middle section" with the "middle section" flange marking the transition. The inner sample removal shell will be installed concentrically within the outer shell. Between the outer shell and the inner shell, permanent wiring will be installed for capsule and sample instrumentation. This wiring enters the capsule through the "middle section" and continues to the back plate of the "rear section". Electrical jumper connectors are installed on the end plate. The end plug will be placed in the inner shell and will consist of shielding material (streaming barrier), electrical leads and secondary helium seal. This plug will extend from the end of the "rear section" to the "middle section" at the helium inlet line connection point. At this point, a seal will prevent leakage of helium to the vacuum gap.

a) Materials

The outer shell, inner shell and end plug will be constructed of AISI type 300 stainless steel.

b) Design

1) The outer shell will be designed to resist forces due to insertion and normal handling stresses.

2) The inner shell will be designed to resist forces resultant from specimen and end plug insertion.

3) The end plug will be designed to provide a barrier for neutron streaming and to resist internal pressure.

2.2 Capsule Insertion Equipment

So that experiments can be inserted into horizontal through tube HT-2 as well as HT-1, the insertion equipment for HT-2 will be designed and installed with the equipment for HT-1. For capsule insertion and removal, there will be three capsule insertion trays used in conjunction with the existing PBRF vapor container overhead polar crane. One tray will service HT-1, one HT-2 and a third the quadrant wall 12-inch tube. These loading trays are illustrated in Figure 1.

The reactor through tube insertion trays will be essentially identical except that the tray for HT-1 will accommodate an 8 1/2" capsule while the tray for HT-2 will accommodate an 11 1/2" capsule. The major components will be constructed of stainless steel. Each unit will consist of a drive slide rail supported by a framework of welded pipe. Feet welded to the bottom of the framework will be bolted to baseplates secured to the quadrant floor. The drive slide rail will house the lower section of a drive slide and guide it by means of machined ways. The end of the rail will not be secured to the end of the through tube; hence, the resultant forces of capsule insertion and withdrawal will be transmitted to the quadrant floor. The upper section of the drive slide will clamp onto the center section of the capsule assembly and transmit the insertion and withdrawal forces of the drive slide to the capsule.

The drive slide will be driven by a worm shaft running through the drive slide and supported on the through tube end of the loading tray by a bearing. The opposite end of the drive shaft will be driven by a constant speed AC electric motor and reduction gear secured to the slide drive rail and tray framework. The design speed of the drive assembly will be consistent with requirements for safe capsule insertion and withdrawal. Provision is made for manual operation of the drive mechanism for capsule withdrawal in the event of power failure to the drive motor.

Electrical interlocks operating in conjunction with mechanical stops on the trays will prevent the capsule from passing certain critical positions during insertion or withdrawal until the interlocks are defeated and the stops released.

Torque switches will prevent overloading the electric drive motor, damage to the capsule or through tube valve or seal.

The quadrant wall tube insertion tray will be constructed and will operate similarly to the through tube insertion trays and will have the ability to handle either a front or rear loading capsule with minor modification. It will be hinged at the quadrant wall tube so that it can swing back against the outer quadrant wall during reactor shutdown to allow space for PBRF fuel cart transit in the quadrant. The capsule will be lifted by means of a device which will attach to the capsule "middle section" and the overhead crane. The capsule will be transferred from one tray to another in this manner during operation and provide for capsule handling during system installation and maintenance.

An aluminum console containing the insertion equipment local controls and instrumentation will be located on the northwest side of quadrant "C" on the 0 ft. level near the overhead crane controls. This console will be on wheels so that it can be moved to the edge of quadrant "C" to afford the operator a view of the underwater operations.

2.3 Hot Cave

To remove the sample from the capsule, a hot cave will be required. The sample removal hot cave shown in Figure 1 will be located in area 17 outside and adjacent to the quadrant "C" wall. It will be of a semi-permanent type construction which will consist of a 1/2" thick welded steel enclosure with a roof which will mate with the quadrant wall, area 17 floor, and area 17 outer wall. These joints will be sealed to provide a gas tight enclosure around the two 12" quadrant wall tubes. The entire unit will be secured to the walls to hold the cave in place against a small internal helium pressure. The steel box will be surrounded with stackable 8" thick, interlocking, high density concrete blocks. Shielding will be designed to maintain minimum personnel exposure never exceeding PBRF maximum allowable levels. All hot cave penetrations except the two 12" quadrant wall tubes will be welded to the steel enclosure to provide support of penetrating equipment and insure gas tight joints.

The cave will contain a permanent radiation monitoring device with an indicator at the hot cave and an indicator and recorder in the experiment control room. Radiation monitoring will be supplemented by portable equipment used during hot cave operation.

The helium inerting system, to avoid contamination of the cryogenic system, will consist of a tap off the cryogenic system supplying the hot cave via tubing and a pressure regulator. The system includes a water filled manometer device which will provide hot cave pressure indication as well as pressure relief capabilities.

A standard liquid zinc bromide window will be installed in the front wall of the hot cave above the capsule centerline which will provide personnel radiation protection and a suitable view of the capsule rear end and remote handling equipment.

Remote handling tools will penetrate the hot cave wall through an indexing drum device which can be manipulated to bring the tool to be used into position. The indexing drum will be located on the capsule centerline below the window.

A drain and collection system will route and contain quadrant water drained from the quadrant wall tube during capsule insertions and any leakage of quadrant water into the hot cave through the seal. The container will have a level indicating device and will be constructed so that it may be handled as contaminated waste should conditions warrant.

A phone system will be installed near the hot cave so that communications may be maintained with the experiment control room and the insertion control station during hot cave operation.

2.4 Horizontal Through Tube (HT-1) Sealing System

The quadrant "A" end of HT-1 will be sealed to prevent primary coolant leakage into quadrant "A". The quadrant "C" end of HT-1 will contain a valve, an inflatable seal, a flange, a primary coolant connecting line and wear strips.

2.4.1 Gate Valve

A gate valve will be installed on the through tube to insure against primary coolant water flow from the through tube to the quadrant. This valve will be remotely operated and will be closed except during periods of capsule insertion and irradiation.

2.4.2 Inflatable Seal

On the quadrant "C" side of the gate valve, an inflatable seal will be installed. To insert the capsule into the through tube, the gate valve must be opened. To insure against primary coolant flow into the quadrant, the inflatable seal will be secured on the capsule before the valve is opened. When the valve is open, the remotely operated inflatable seal will be the primary seal between the through water and quadrant "C" water.

2.4.3 Backup Seal

The backup seal will be a gasketed flanged joint. The through tube flange will mate with the capsule flange at the fully inserted position and will act as a backup for the inflatable seal.

2.4.4 Coolant Water Connecting Line

A connecting line will be installed to provide adequate cooling water for the capsule shell when the capsule is in the through tube. This line will include remotely operated valves which will control cooling water input into the tube and insure against uncontrolled coolant discharge into the quadrant. This line will provide coolant flow in the through tube past the capsule from front to rear toward quadrant "C".

2.4.5 Wear Strips

Removable wear strips will be installed in the through tube from the quadrant "C" end of the tube to the approximate centerline of the core. These strips will insure proper positioning of the capsule and prevent any displacement of the capsule while in the through tube. Also these strips will protect the through tube from damage or wear associated with insertion and removal.

2.5 Sample Handling Description

2.5.1 Hot Cave Preparation

Subsequent to irradiation of a test sample, the "rear" section" of the capsule will be inserted into the quadrant wall tube (shown in Figure 1), secured, sealed, depressurized and warmed up. Prior to receiving the capsule, the hot cave (shown in Figure 1) will have been set up with a new sample, necessary replacement parts and will have been inerted to insure a substantial helium atmosphere to prevent contamination of the cryogenic system.

2.5.2 Capsule Sample Replacement

The hot cave remote tool indexing drum will be positioned, and the capsule end electrical jumpers will be removed and secured to a stowage rack within the cave. The indexing drum will be repositioned, and the end plug will be removed and transferred to its stowage rack. As the sample is withdrawn, the sections of the sample pull rod will be disconnected and transferred to the stowage rack in the hot cave. The last section with the sample attached will be withdrawn from the capsule and set into the water tight sample transfer container with its electrical and instrumentation leads. The container cover will be installed, and it will be transferred back into the quadrant through the adjacent 12" tube for subsequent transfer to the PBRF hot cells for examination and testing.

The sample transfer container with a new sample will be swung into position, and its cover will be removed. The sample, with new electrical and instrumentation leads attached, will be withdrawn from the container and inserted into the capsule. The sample will be pushed into the capsule with its wires trailing as pull rod sections are connected. Finally, the end plug will be attached to the pull rod; and the entire unit will be inserted to its final position and the end plug secured.

The electrical and instrumentation lead jumpers will be installed.

After electrical and instrumentation lead checkout, pressure and vacuum testing, the capsule will be withdrawn from the quadrant wall tube and cooldown will be started.

2.6 Quadrant Wall Tube Sealing System

Two tubes existing in the quadrant "C" wall will be used for sample removal and transfer. One tube will be used for capsule insertion to the hot cave. This tube will contain a valve and flange on the quadrant side and a swing door on the hot cave side. The second tube will be used for sample transfer from the hot cave back to the quadrant water. This tube will contain a similar swing door on the hot cave side and valve on the quadrant side.

2.6.1 Sample Removal Tube

a) Flange - On the quadrant side a gasketed flange will be installed on the existing tube. This flange will be forced against the capsule flange upon capsule insertion to the hot cave; and during sample removal, it will be the primary seal between the quadrant and hot cave.

b) Valve - A remotely operated valve will be installed between the flange and the wall on the tube. This valve will be closed providing the primary seal between the hot cave and quadrant except during periods of capsule insertion and sample removal.

c) Swing Door - A water tight hinged closure will be installed on the hot cave side of the tube. This door will be closed until the flange connection is made between the tube flange and capsule flange. The tube will then be drained of water, and the door will be unlocked and opened for sample removal. After sample removal, the procedure will be reversed and the swing door locked. This door will now provide a backup for the valve on the quadrant side. Interlocks will be installed on the swing door and flange connection to insure a proper seal before opening the door and to guarantee that quadrant water will not be drained into the hot cave.

2.6.2 Specimen Transfer Tube

a) Swing Door (1) - On the hot cave side of the tube, a water tight hinged closure will be installed similar to the sample removal tube door. This door will be opened so that the sample transfer container can be inserted into the tube. The door will then be locked in place.

On the quadrant side of the through tube, a remotely operated valve will be installed. After the swing door is secured, this valve will be opened so that the sample transfer container can be moved into quadrant "C" from the tube. This valve is the primary seal between the quadrant "C" water and the hot cave. The swing door on the hot cave side will be a backup seal, and both closures will be designed to resist the quadrant water pressure.

2.7 Environmental Control Systems

The two primary variables to be controlled in the loop are mass flow rate and capsule inlet temperature. The flow paths through the capsule are shown in Figure 8. Compressor inlet pressure, secondary flows and expander load will be manipulated within design limits to achieve the desired mass flow rate. Secondary flows and expander load will be varied to control capsule inlet temperature. In addition, it may be convenient to throttle the return leg of the primary coolant in order to regulate coolant velocities in the capsules. It may also be convenient to throttle a bypass coolant flow for fine control of the mass flow rate.

2.7.1 Control System Operation

The system cooling will be initiated with the capsule outside the reactor. The compressor startup bypass will be opened to minimize starting load on the compressor. The compressor house layout is shown in Figure 10. During steady-state operation, the automatic flow control will be from the regulator valves on the gas storage bottles and the relief valve on the compressor inlet and possibly a bypass throttling valve. The automatic temperature control at the capsule inlet will be accomplished by controlling the load on the expander, probably by varying the field on a generator which is driven by the expander and which dumps energy into a fixed load bank.

2.7.2 Auxiliary Equipment

Auxiliary equipment for the loop is of two types: loop support equipment and capsule handling equipment. Loop support equipment includes vacuum equipment, liquid nitrogen equipment, cooling water equipment, helium storage bottles and the load bank. The capsule handling equipment includes equipment in the loading cave and underwater handling equipment in the quadrant. The auxiliary equipment is operated manually or by remote controls. Indications are sent from the equipment to the loop control panel or the capsule handling panel.

The speed of capsule insertion into the reactor is inherently limited by the insertion motor which cannot exceed synchronous speed at power line frequency. The speed of withdrawal is similarly limited. Insertion and withdrawal can be controlled locally in the reactor building at the capsule handling panel; withdrawal can also be initiated via the loop control panel.

2.7.3 Instrumentation

The instrumentation will consist of:

a) loop temperature, pressure and flow indicators and recorders,

b) capsule temperature recorders,

c) vacuum jacket pressure, coolant flow, expander load, valve position and compressor voltage and current indicators,

d) low flow, loss of vacuum, high capsule outlet temperature, high compressor inlet or outlet pressure, high filter ΔP, high capsule ΔP, low He bottle weight and low liquid nitrogen level alarms.

The controllers are as previously described.

2.7.4 Experiment-Reactor Interlocks

Alarms will be provided to notify reactor operators of loop trouble, and preparations will be made for withdrawal of the inpile section. Procedural restrictions will prohibit manipulation of the inpile section during planned changes in reactor power, but no automatic interlocks are planned.

3.0 Hazards Evaluation

3.1 Philosophy of Operation

It is intended that the design of the capsule insertion and removal system will be such that a single experiment operator can easily and rapidly carry out an emergency withdrawal of the capsule to protect the reactor both from damage, and from unnecessary shutdown in situations where an experiment parameter is approaching an excessive value. This type of removal would be carried out only with the appropriate approval and assistance of the reactor operating crew.

While it is hoped that the removal capability described above will make it possible to handle experiment problems without requiring a reactor shutdown, the possibility always exists that an abnormal condition may develop too rapidly to cope with in this manner. Therefore, certain experiment conditions should cause an automatic reactor shutdown. A tentative list of these is given below:

Helium Flow-Low
Helium Temperature-High
Helium Pressure-Low
Experiment Power Failure
Through Tube Coolant Flow-Low
Secondary Coolant Flow-Low

3.2 Specific Postulated Accident

3.2.1 Maximum Credible Accident

The investigations of possible accidents so far performed have not resulted in determining any situation which is clearly the maximum credible accident. However, it appears that the maximum effect the experiment could have on the reactor is through its influence on reactivity, which is discussed below.

Prior to the initiation of any of the NERVA irradiation tests conducted in HT-1, reactivity worth tests will be run on the actual capsule (or a mockup of same) in the PBRF critical facility. All pressure, temperature and flow ranges corresponding to normal operating limits will be used in conjunction with a representative sample. In addition, a reactivity test will be accomplished prior to the initiation of any individual run if calculations indicate that the specific sample might have a greater reactivity ffect than the representative sample.

a. Capsule Insertion and Withdrawal Rates

The capsule will be inserted into and removed from HT-1 at the same speed. The speed will be the same for all tests indicated in Section 2 of this report. The insertion speed finally selected will be based on measured control rod and predicted capsule worths with appropriate leeway retained for reasonably absorptive samples. However, capsule drive motors may be changed if experiments not currently listed are found to have exceptionally large reactivity effects, or if predicted reactivity values are found to be incorrect. The speed selected is one foot/min. This is based on; a total inserted reactivity change of 1% $\Delta k/k$; 0.1% Δk/inch; and a minimum controlled Δk reverse rate of 1.2% Δk/min.

b. Accidental Capsule Ejection

A 1% change in reactivity occurring upon accidental ejection of the capsule from HT-1 can be controlled. The minimum reactivity insertion time for which control of a 1% Δk change can be maintained is approximately 0.15 sec.*

The nominal 50 gpm cooling water flow rate in HT-1 could sustain a capsule ejection velocity of only 0.283 ft/sec. Hence, in excess of 7 sec. would be required for the insertion of 1% $\Delta k/k$ if all the flow were effective in moving the capsule.

An orifice plate or tube in the water inlet line and a check valve in the outlet line will assure that the maximum flow of water to HT-1 will be limited to a safe value with respect to capsule ejection velocity.

*BRF Final Hazards Summary, Part III, Figure I 27, P. 191

3.2.2 Loss of Helium Flow

A loss of cooling flow to the sample and capsule internal pressure containing wall (helium envelope) will not result in an unsafe condition for the sample, capsule or reactor. However, to preserve the integrity of the pressure containing helium envelope, the reactor power should be reduced upon a loss of flow.

An undesired loss of flow could result from a compressor or expander outage or an inadvertent closing of either of the capsule isolation valves. Reactor power reduction will be initiated by signals from the following sensors: compressor power, expander load, capsule differential pressure.

As a result of loss of flow but with continued gamma heating of the sample, sample shroud, and helium envelope, all metal temperatures would rise. Some heat would be transferred to the stagnant helium by natural convection, but heat could not be transferred to the (outer) water-cooled capsule wall because of the vacuum gap between that wall and the helium envelope. Heat transferred to the stagnant helium would raise its temperature and pressure. However, the capsule safety valve would protect against pressurizing the helium envelope above the 130 psia design pressure.

Analysis of the incident is based on the following assumptions: all heat generated in the helium pressure containing wall goes to increasing the wall temperature; full power heat generation continues for one full second after the cessation of flow and thereafter decreases to 2% during 1.16 seconds; initial average wall temperature is 100°F. Full power heat generation is assumed to follow a cosine distribution with a maximum of 12 w/gm at the core centerline.

Results of the analysis indicate that the maximum wall temperature reached under these conditions will not be sufficient to cause failure of the helium envelope wall due to the reduced strength at the elevated temperature.

3.2.3 Experiment Power Failure

This will result in complete loss of coolant circulation. Even if the outage is a local one affecting only loop circuits, the reactor will be shutdown by a shutdown signal from the experiment. The situation then becomes that analyzed under loss of coolant flow. It is planned to supply emergency power to the capsule insertion and withdrawal system, and to certain critical measuring and control devices.

3.2.4 Loss of Secondary Coolant Flow

This will require a rapid (and probably automatic) shutdown of the helium compressors, which causes the "Loss of System Coolant Flow" previously discussed.

3.2.5. Handling Accident

The materials and components to be tested in the initial phase of operation of this experiment (covered by this document) are unfueled solids and the production of radioactive liquids and gases is expected to be negligible. On this basis a handling accident which could result in serious injury or damage is not expected.

3.2.6 Instrument Failure

As far as possible, all measuring devices will be "fail safe", so that upon the most probable mode of failure, the indication will be that which is least desirable. In addition, any measuring device whose output might call for a reactor shutdown will be provided with a "backup".

3.2.7 Control System Failure

As in the case of measuring devices, all control elements will be as "fail safe" as possible. Regardless of this, the worst situation a control system malfunction could produce is considered to be a "Loss of Helium Flow" either by compressor shutdown or valve closure.

3.2.8 Chemical Reactions

All materials involved in both the test specimens and the loop components are inert chemically in the environment to which they will be exposed.

3.2.9 Boiling

The possibility of boiling the cooling water in HT-1 has been considered and is discussed below.

3.2.9.1 Normal Operating Conditions

The outlet temperature of the cooling water in HT-1 will be substantially less than the the saturation temperature at the minimum outlet pressure. This is because the total amount of heat generated in the outer capsule wall and the HT-1 wall (taken at a 12 w/gm gamma heating rate throughout) is considerally less than the heat dump capacity of the 50 gpm cooling water flow. The surface temperature of the capsule will be somewhat less than 250°F. Consequently, neither saturated nor subcooled boiling of the cooling water can occur under normal operating conditions.

3.2.9.2 Loss of HT-1 Cooling Water Flow

A loss of cooling water flow could conceivably occur as a result of a blockage of the radial gap between the capsule and through tube walls or an inadvertent closing of the valve in the HT-1 inlet line. This would result in a subcooled nucleate boiling regime.

A reactor power reduction will prevent boiling under these circumstances. Power reduction will be initiated by signals from water flow and pressure sensors. Hence, no unstable reactor condition due to void formation could result from a loss of cooling flow.

3.2.9.3 Loss of HT-1 Cooling Water

A loss of coolant from HT-1 or from the portions of the coolant inlet and outlet lines between HT-1 and the isolation valves in the lines could occur. Depending on the location of the rupture, the result would be similar to a loss of coolant flow, covered above, (inlet line rupture with check valve in outlet line preventing backflow) or would constitute a condition of increased flow past the capsule (outlet line or capsule seal failure). A decrease in the water pressure, tending to reduce the time to initiation of boiling, would occur in either case. However, in the latter case, the increased flow past the capsule and the power reduction caused by the low flow alarm would preclude the possibility of boiling the coolant (the flow meter initiating the low flow alarm is located downstream of the check valve, thus protecting against loss of coolant as well as loss of flow incidents).

3.2.10 Capsule Failure

While the capsule is in the through tube, capsule failure may occur from either the external pressure of the coolant water (160 psi) or the internal pressure of the helium system.

3.2.10.1 External Shell

Failure of the external shell will expose the inner shell (helium envelope) to excessive external pressure, probably causing it to collapse in some unpredictable fashion. This may result in partial or complete blockage of coolant flow; but this should not cause excessive temperatures to develop, particularly since a reactor shutdown will take place. Improved heat transfer conditions will exist due to filling of the capsule with water.

The reactivity effect of flooding the capsule void must also be considered. From the calculations of similar flooding situations presented in the PBRF Final Hazards Summary, it is expected that this effect will be small and controllable; however, measurements of flooding effect will be made before experiment operation.

Another result of this failure would be the possibility of the passage of radioactive primary coolant water up the annular vacuum spaces in the coolant lines, and possibly the coolant passages themselves. This could produce excessive radiation levels in occupied areas. However, the dose rates due to this occurrence should be such that standard radiation monitoring; and evacuation procedures will prevent overexposures.

3.2.10.2 Inner Shell (Helium Envelope)

Failure of this shell will flood the vacuum insulating space with low temperature helium, chilling the external shell and possibly producing some water freezing on its outside surface. However, any ice formation should be small and of very short duration, since the maximum heat removal capacity of the system at 32°F is approximately 200 KW, whereas the heat available from through tube cooling water, if cooled to 32°F, will be approximately 1000 KW.

The failure of the helium envelope should not jeopardise the external shell structural qualities, since the latter is designed for (and subjected to) 160 psi external pressure and will withstand the approximate 115 psi internal pressure of the helium system.

3.2.11 Reactor Excursion

A reactor excursion of 10 milliseconds as described in the PBRF Final Hazards Summary is calculated to produce a maximum temperature increase in the capsule of 26°F. This rise in temperature should not cause any failures in the experiment.

TABLE I

NERVA IRRADIATION TEST PROGRAM (5)

Test	Thermal Neutron Flux $n/cm^{-2}sec^{-1}$	$(nv_e)\ t$	Fast Neutron Flux $n/cm^{-2}sec^{-1}$	nvt	Gamma Flux ergs $gm^{-1}(C)hr^{-1}$	ergs^{-1}(C)	Temp. (°R)	Irradiation Time (Hr)
Instrumentation Components								
Accelerometers	6×10^{14}	1.1×10^{20}	3×10^{14}	5.4×10^{19}	8.8×10^{10}	4.4×10^{12}	130	
Displacement Transducers	6×10^{14}	1.1×10^{20}	3×10^{14}	5.4×10^{19}	8.8×10^{10}	4.4×10^{12}	130	50
Resistance Thermometers	6×10^{14}	1.1×10^{20}	3×10^{14}	5.4×10^{19}	8.8×10^{10}	4.4×10^{12}	130	50
Strain Gages	6×10^{14}	1.1×10^{20}	3×10^{14}	5.4×10^{19}	8.8×10^{10}	4.4×10^{12}	130	50
Thermocouples								
Chromel/Alumel & Copper/Constantan	6×10^{14}	1.1×10^{20}	3×10^{14}	5.4×10^{19}	8.8×10^{10}	4.4×10^{12}	130	50
Mechanical Components								
Aluminum Barrel-Graphite								
Cylinder Shrink Fit			3×10^{14}	5.4×10^{19}			38	50
Coil Springs			3×10^{14}	5.4×10^{19}			38	50
Control Drum								
Assembly			3×10^{14}	5.4×10^{19}			38	50
Bearing			3×10^{14}	5.4×10^{19}			38	50
Bearing (dynamic)	2×10^{14}	1.4×10^{18}	3×10^{14}	5.4×10^{19}			50	2
Lateral Support Assembly			3×10^{14}	5.4×10^{19}			38	50
Leaf Spring Seal Section			3×10^{14}	5.4×10^{19}			38	50
Molybdenum Instrumentation Tubes			3×10^{14}	5.4×10^{19}			38	50
Outer Reflector Support Ring			3×10^{14}	5.4×10^{19}			38	50
Shield Capsules			3×10^{14}	5.4×10^{19}			38	50
Structural Materials			10^{13}	10^{20}			50	50

FLUID UTILITY REQUIREMENTS

Utility	Use	Flow Rate
Primary Water	Beam Hole Cooling	50 (gpm)
Secondary Water	Loop Heat Removal	200 (gpm)
Service Air	Inst. and Control	10 (ft^3/min)

TABLE II

ELECTRICAL POWER REQUIREMENTS

Type of Power	Use	Power (KW)
4160 V 60~ 3 φ	Loop Compressor	1000
Emergency Power 480 V 60~1 φ	Instrumentation and Control Devices	25
120 V 60~1 φ	Instrumentation and Control Devices	25

TABLE III

REFERENCES

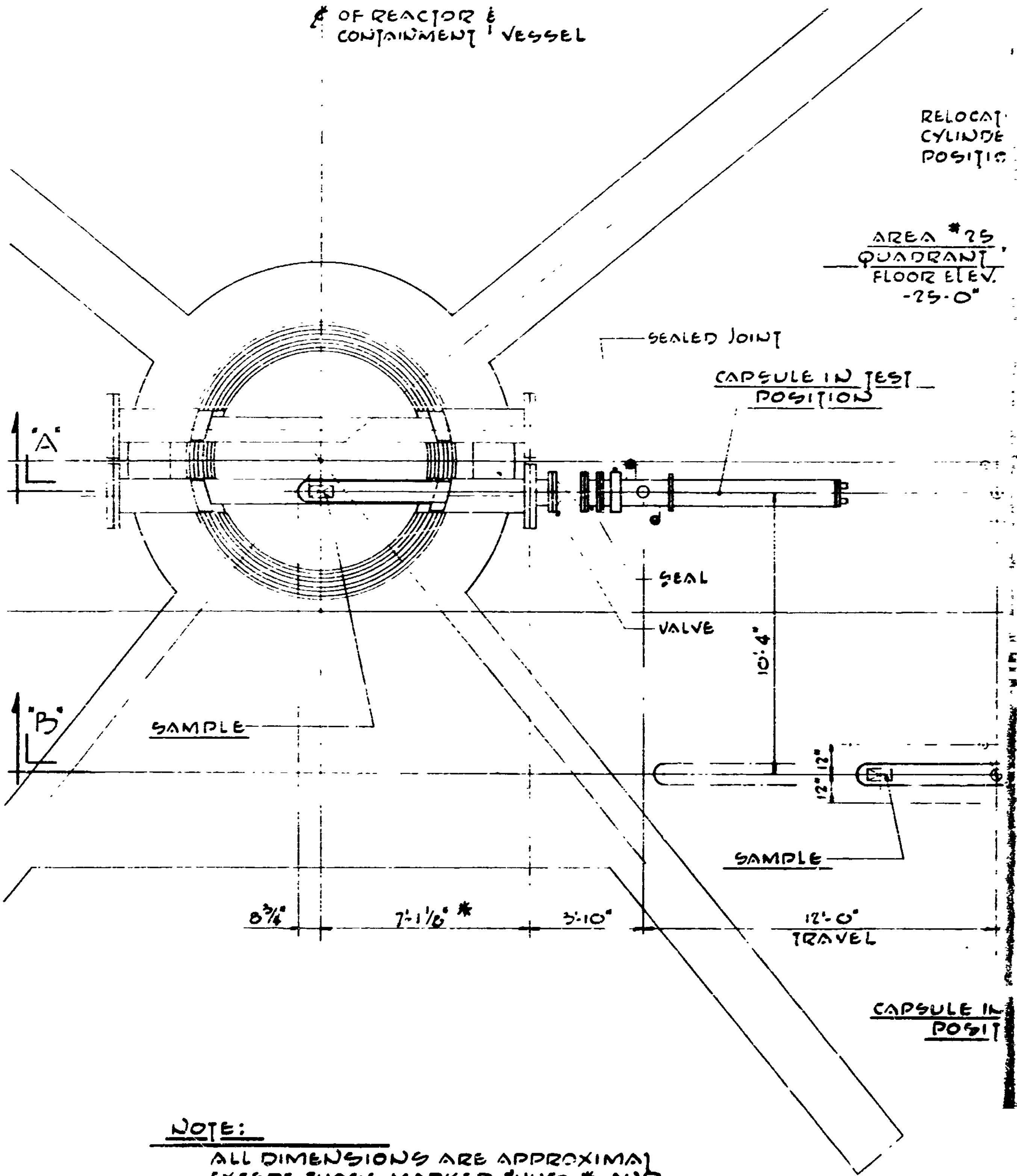
1. NASA - Plum Brook Reactor Facility Hazard Summary Report, Lewis Research Center - Staff, Parts I, II, III, 12/62.

2. WANL-TME-113, Preliminary Proposal to PBRF for NERVA Radiation Effects Program, 8/30/62.

3. WANL-TME-144, Preliminary Proposal to PBRF for the NERVA Radiation Effects Program, 8/13/62.

4. WANL-PL-066, Proposal for the Utilization of PBRF for the NERVA Radiation Effects Program, 11/20/62.

5. WANL-TME-201, Request for Irradiation at PBRF, S. S. Stein, 11/13/62.



NOTE:
ALL DIMENSIONS ARE APPROXIMAT
EXCEPT THOSE MARKED THUS * AND
BUILDING OUTLINE DIMENSIONS

General Arrange

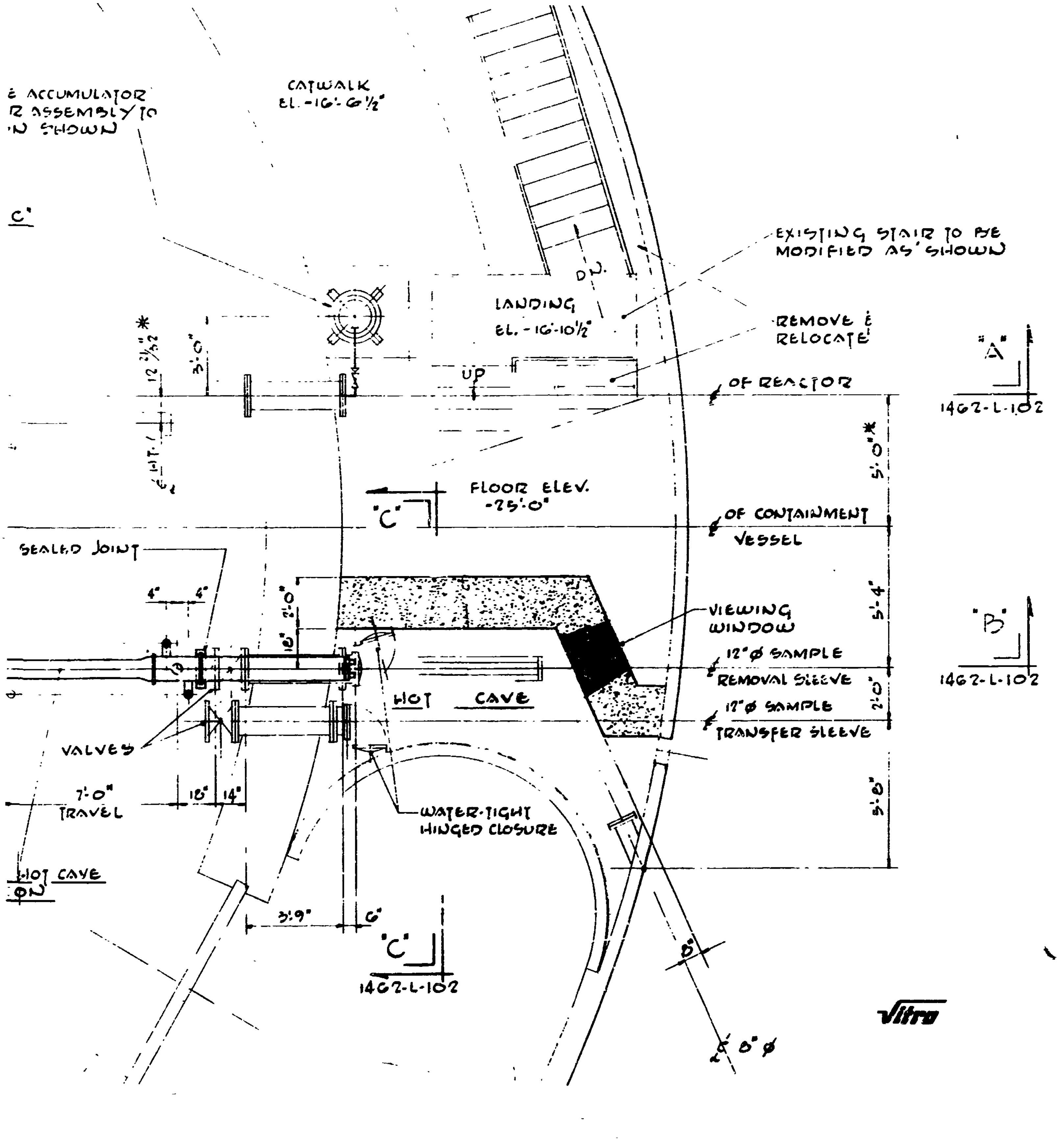
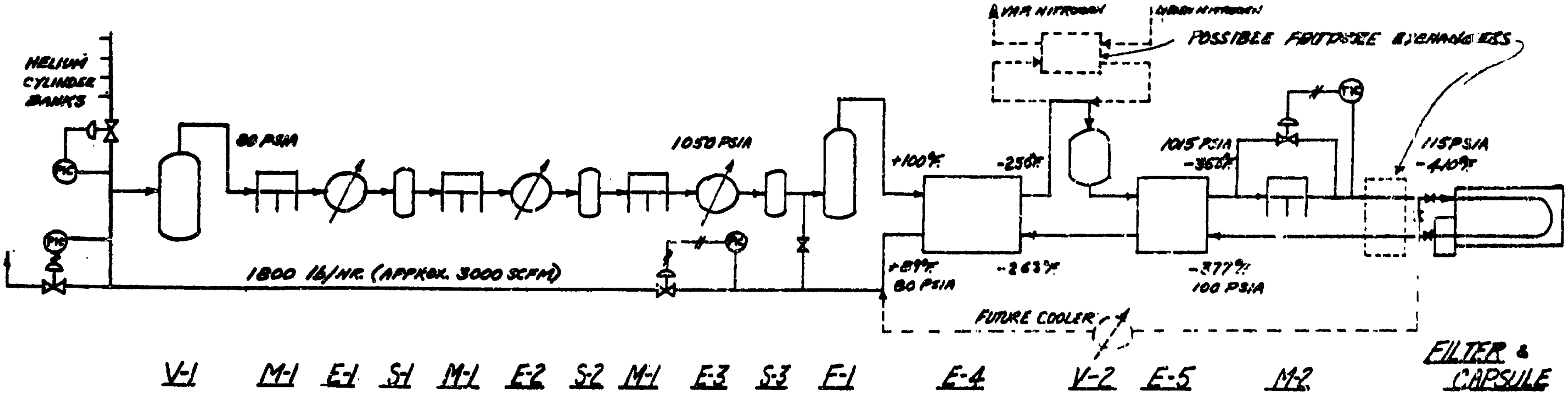


Fig. No. 1

...nt - Plan Inside Containment

2



MAJOR EQUIPMENT ITEMS

V-1	HELIUM SURGE DRUM
M-1	3-STAGE OIL LUBRICATED RECIPROCATING COMPRESSOR, MOTOR DRIVEN, APPROX. 800 H.P.
E-1	COMPRESSOR 1ST STAGE INTERCOOLER (MOUNTED ON COMPRESSOR)
E-2	" " 2ND " " " " " " "
E-3	" " AFTERCOOLER " " " "
S-1	" " 1ST STAGE OIL SEPARATOR " " " "
S-2	" " 2ND " " " " " " " "
S-3	" " 3RD " " " " " " " "
F-1	FINAL OIL FILTER (KNOCK-OUT DRUM + MESH + ACTIVATED CARBON + POROUS METAL + FIBERGLASS MATS)
V-2	SILICA GEL TRAP FOR REMOVAL OF HIGHER BOILING MATERIALS.
E-4	WARM EXCHANGER
E-5	COLD EXCHANGER
M-2	1-STAGE NON-LUBRICATED RECIPROCATING EXPANSION ENGINE

PRELIMINARY

WESTINGHOUSE ELECT. CO. ASTRONUCLEAR LAB	HELIUM REFRIGERATION CYCLE FOR ENVIRONMENTAL TESTS AT PLUM BROOK FACILITY
DRAWN BY: NGF DATE 12/4/62 ENGINEER NGF DATE 12/4/62 APPROVED [illegible] DATE 12/9/62	DRAWING No. SK-002

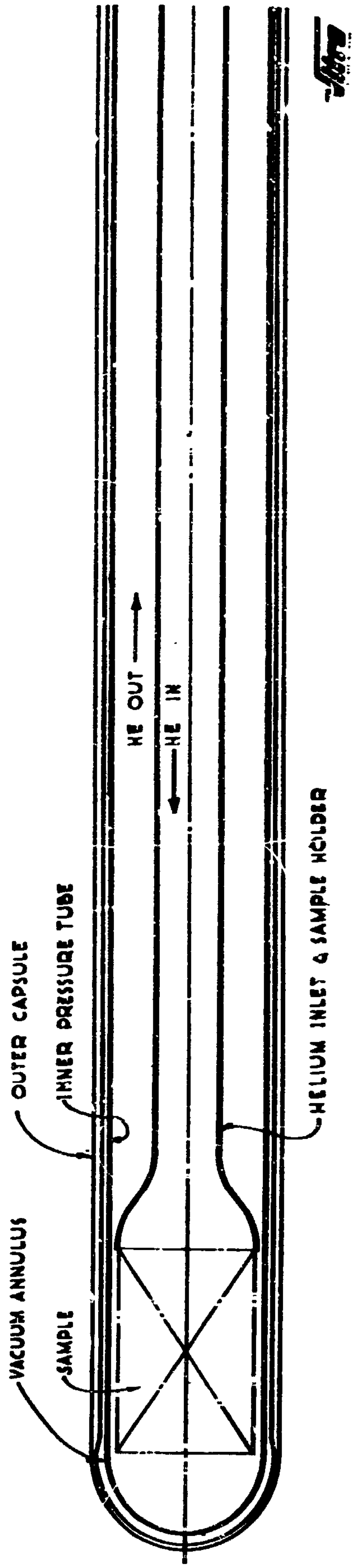
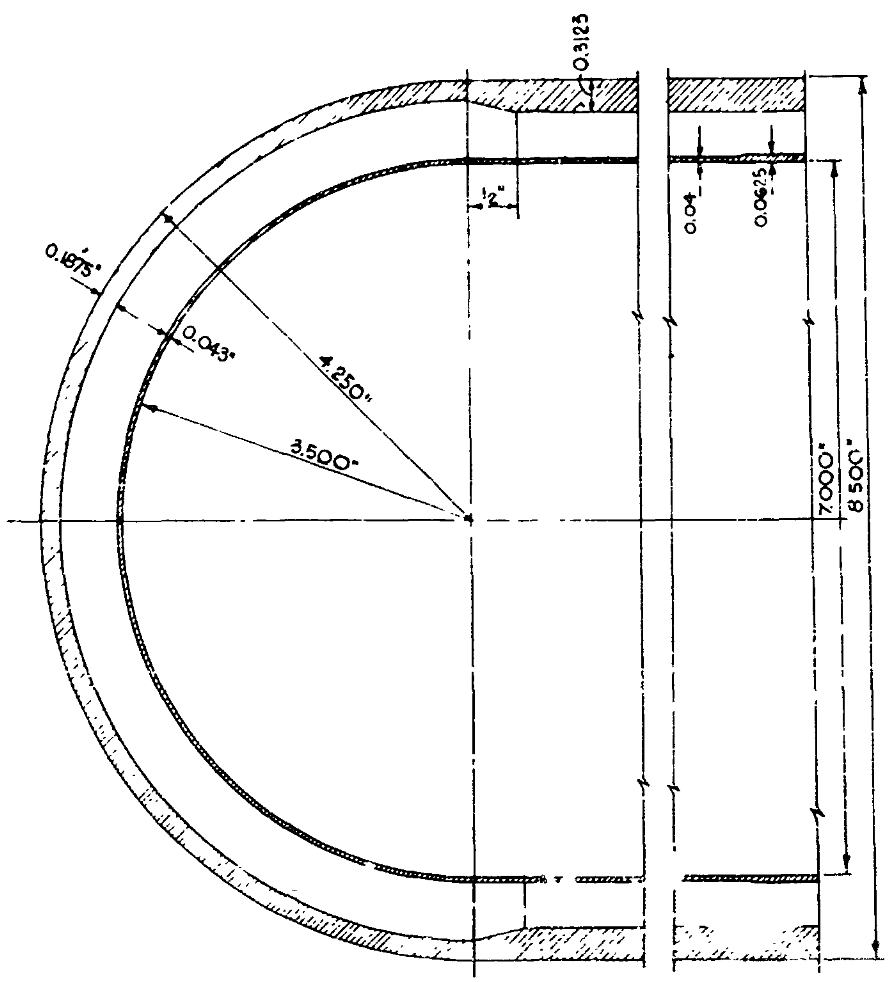


Fig. No. 4

Capsule – Sample End



Vitro

Fig. No. 5

Capsule - Enlarged Section - Sample End

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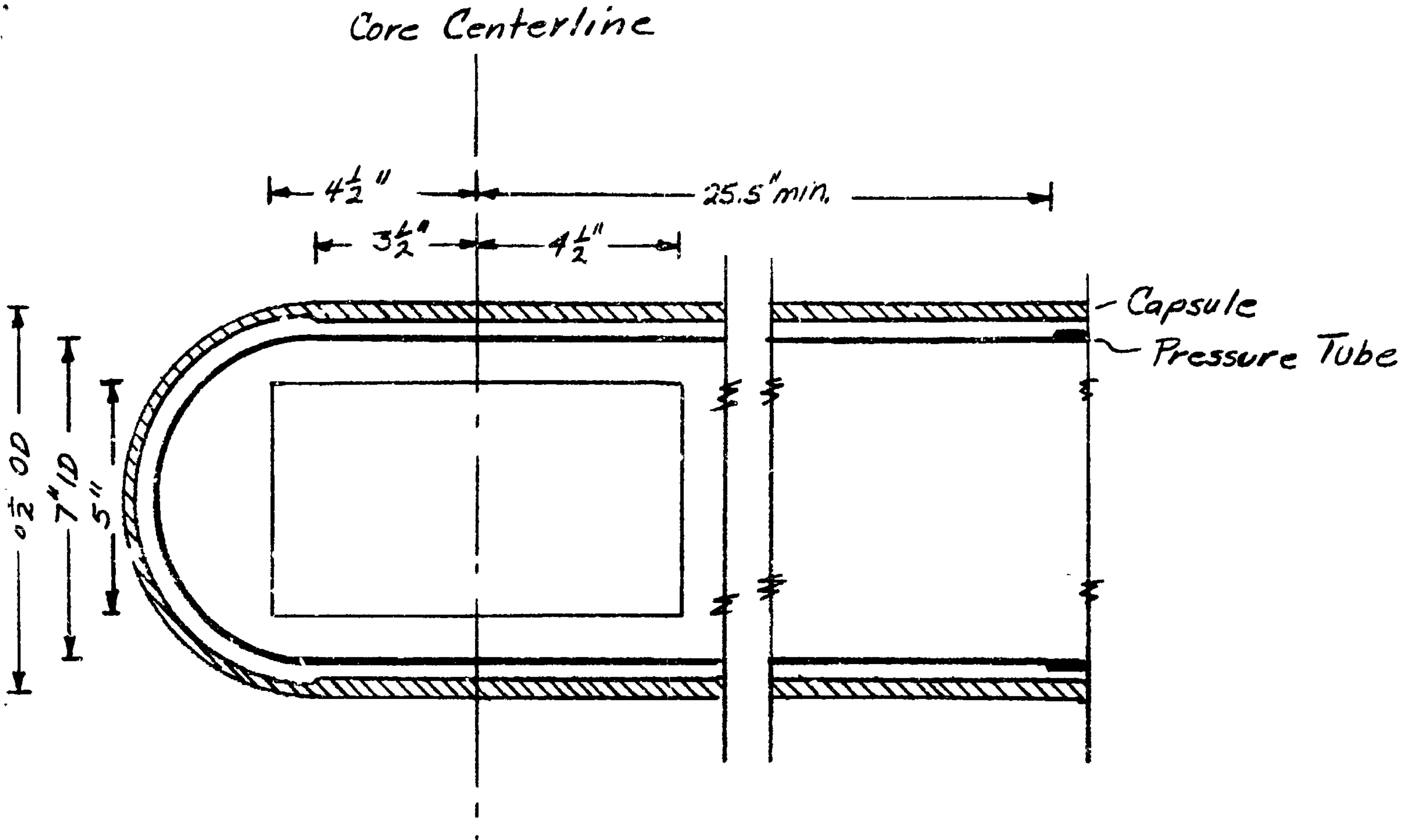

Wall thicknesses

Capsule (Al 6061 T6)

hemispherical head 3/16"

cylindrical shell* 5/16"

Pressure Tube (Al 6061 T6)

head & cyl. shell .043"

* wall thickness increased to 1/16" thickness 25.5" from core centerline

Fig. No. 6

In Core Section of Capsule

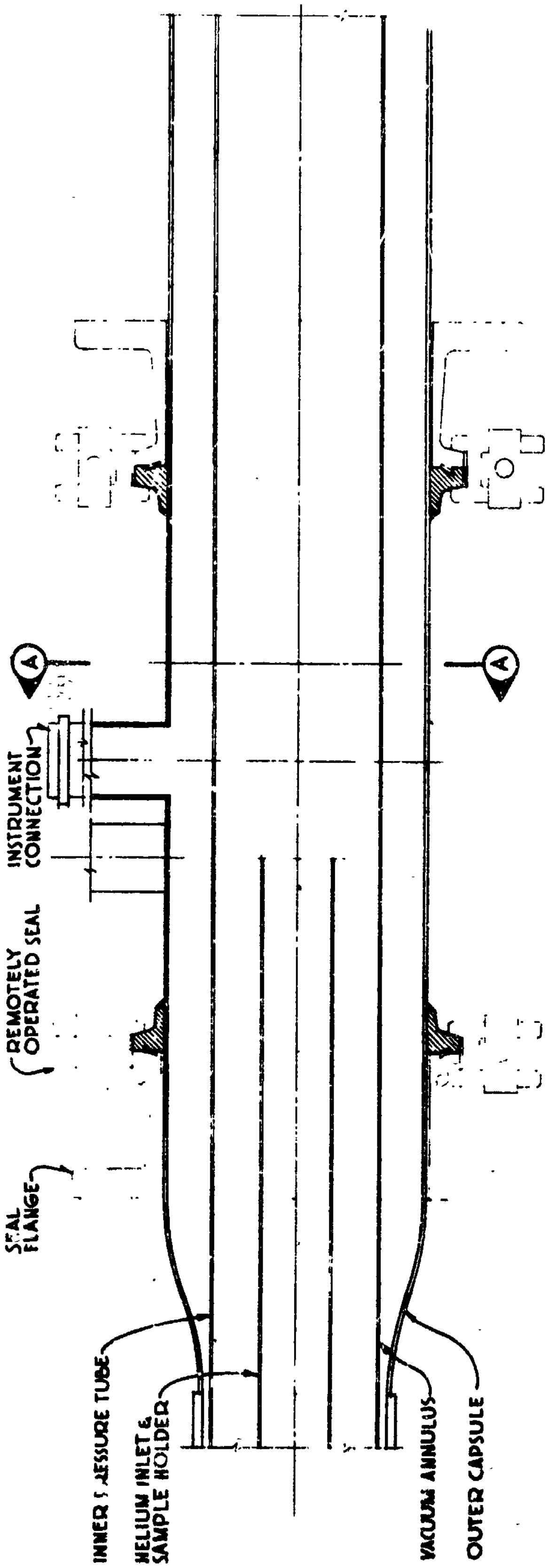

Fig. No. 7

Capsule - Middle Section